# Deflecting efficiency of a kicker with plane or cylindrical electrodes

A.Shemyakin, M. Sutherland

*Introduction*

The Project X MEBT needs a travelling wave (TW) kicker for bunch-by-bunch chopping [1]. In the present versions, the beam sees a set of parallel plates connected with a TW structure. One of the characteristics of the kicker is its efficiency in deflecting particles at a given electrode voltage and a given length occupied by the kicker. In this paper, the efficiency is calculated in the electrostatic approximation for cases where the kicker electrodes are plates or cylinders. Reasoning behind considering the latter version is that a round structure might be simpler to use in a real technical design, for example, if water cooling is required.

*Model*

All simulations are made in 2D geometry, infinite in $z$ direction and symmetrical with respect to the plane $x=0$. A voltage is applied symmetrically *(±dU)* to two electrodes which surfaces stay at $\pm dx$ ($dx = d/2$) from axis while all other electrodes are at the ground potential.

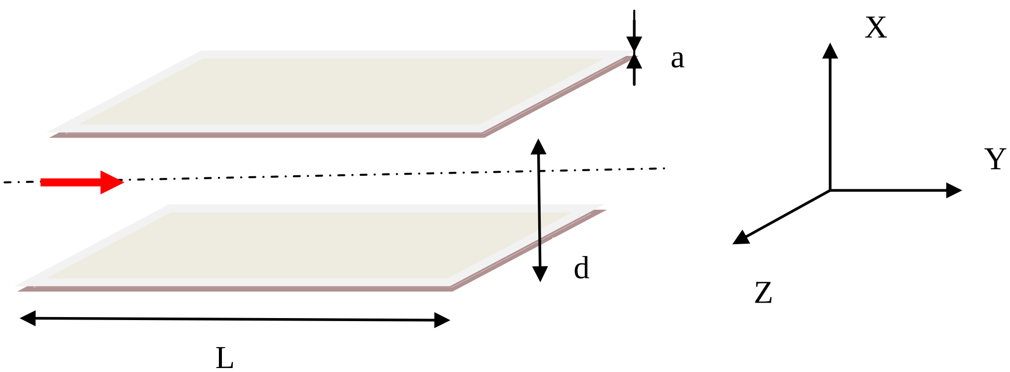


Figure 1. Illustration of the model in the case of two plates.

The beam propagating through the kicker acquires a momentum in $x$ direction equal to

$$p_x = \int_{-\infty}^{\infty} eE_x(z)\frac{dy}{v_y}, \tag{1}$$

where $v_y$ is the particle velocity, $e$ is the particle charge, and $E_x$ is the $x$ component of the electric field. In a small kick approximation, $v_y$ can be considered to be nearly constant, and the Gauss theorem can be applied to express the integral through the total charge per unit length $Q_t$ above the beam trajectory

$$p_x \approx \frac{1}{v_y}\int_{-\infty}^{\infty} eE_x(z)\,dy \approx \frac{e}{v_y}\frac{Q_t}{\varepsilon_0} \tag{2}$$

The charge is proportional to the kicker voltage with some coefficient $C_k$ so that

$$p_x \approx \frac{e}{v_y}\frac{C_k}{\varepsilon_0}\cdot(2\cdot dU)\,. \quad (3)$$

The coefficient $C_k$ characterizes how effectively the kicker uses the available voltage. If the electrode occupies a length $L$ along the beam, it was suggested [2] to introduce a dimensionless kicker efficiency $\eta$ normalizing the kick by the momentum that the particles gets passing through the same length between two long parallel plates with the same gap $d$

$$\eta \equiv \frac{C_k d}{\varepsilon_0 L}\,. \quad (4)$$

For example, for two parallel plates (Fig.1)

$$\eta \approx 1 + k_p\frac{d}{L} \quad (5)$$

with $k_p \approx 1$ [3].

*Simulation geometries and results*

Simulations were performed with SAM code [4]. All geometries (Fig. 2, 3) are symmetrical with respect to the plane $x$=0. The kicker is approximated by three pairs of identical electrodes placed between two long “ground” plates. The voltage is applied symmetrically *(*±*dU*) to the middle pair of the “kicker electrodes”.

The coefficient $C_k$ is calculated for each geometry from the field integral along the line $x=0$ (shown as white lines in Figures 2,3). The results are summarized in Table 1.

Table 1. Kicking efficiency $\eta$ calculated for several geometries of the kicker electrodes.

| **#** | **Geometry** | **L mm** | **d mm** | ***η*** | **$C_{be}$ pF/m** | **$C_{eg}$ pF/m** | **Field width mm** | **Comment** |
|---|---|---|---|---|---|---|---|---|
| 1 | Three pairs of plates | 18 | 18 | 0.99 | 4.9 | 13.0 | 18.7 | See Fig.2 |
| 2 | Three pairs of cylinders, h=0 | 18 | 18 | 0.87 | 7.4 | 8.5 | 20.1 | |
| 3 | Three pairs of cylinders, h=14 mm | 18 | 18 | 0.84 | 2.5 | 30.7 | 19.8 | See Fig.3 |
| 4 | Three pairs of cylinders, h=20 mm | 18 | 18 | 0.63 | 0.2 | 43.6 | 16.5 | |
| 5 | Three pairs of cylinders, h=0 | 29 | 18 | 0.72 | 1.9 | 12.1 | 27.0 | |
| 6 | Two plates | 18[1] | 18 | 2.1 | | | 56.7 | From [3] |
| 7 | Two cylinders of 6 mm radius | 18[2] | 18 | 2.0[3] | | | 70.5 | |
| 8 | Two cylinders with ground plates | 18[2] | 18 | 1.3 | | | 26.5 | |

1 – for calculation of $\eta$, the period $L$ is assumed to be equal to the plate length
2 – for calculation of $\eta$, the period $L$ is assumed to be equal to the gap between cylinders
3- calculated with the analytical formula [5]

Also, the program provides coefficients of the capacitance matrix. Table 1 includes capacitances per unit length between neighboring kicker electrodes (column $C_{be}$) and between the middle electrode and the ground plate (column $C_{eg}$).

The rows 6-7 are included in Table 1 for illustration. Geometries 6 and 7 contain only two electrodes, either two parallel plates (#6) or two cylinders (#7). The geometry #8 differs from #7 by adding two ground plates with the gap (similar to $a_3$ at Fig. 3) of 3.6 mm. While a period per se is not defined for these cases, for the purpose of comparing the kicking efficiency $\eta$ it is assumed be equal to the gap between electrodes (which is equal to the plate length for #6).

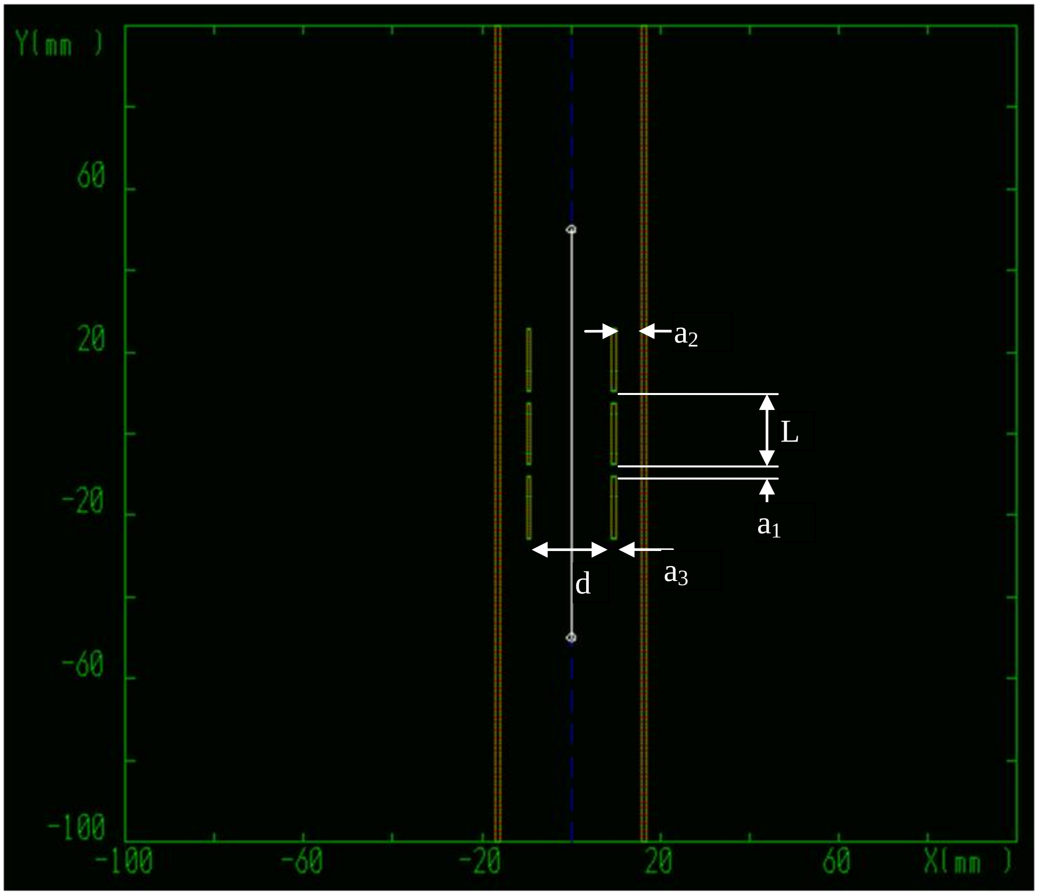


Figure 2. Geometry 1: kicker electrodes are plates. Voltage *(±dU)* is applied between the middle electrodes while other two pairs and ground plates are at zero potential. The gap between kicker plates $a_1 = 3$mm, the distance from kicker plate to the ground plate $a_2 = 6$mm, the kicker plate thickness is $a_3 = 1$ mm.

The column Field Width in Table 1 is relevant to smearing of the edges of the gap created by the kicker in the beam. Even at an infinitely fast increase of the electrode voltage, particles in different initial positions $z_0$ get a different total kick

$$p_x(z_0) \approx \frac{1}{v_y} \int_{z_0}^{\infty} eE_x(z)\, dy \,. \tag{6}$$

As a characteristic of this transitional length, one can consider the distances between initial positions where the integral in Eq.(6) reaches 10% and 90% of its maximum value. This value is indicated in Table 1 in the column Field Width. For example, for the case with plates (Geometry #1) the particles kicked by 90% and 10% are separated by 18.7 mm, corresponding to 0.93 ns at 2.1 MeV.

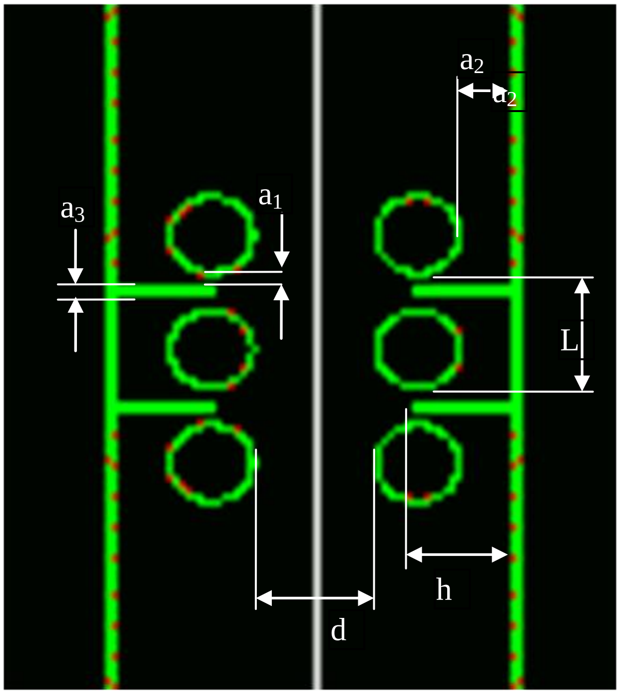


Figure 3. Geometries 2-5: kicker electrodes are cylinders. Voltage *(±dU)* is applied between the middle electrodes while other two pairs and ground plates are at zero potential. The gap between the kicker cylinder and shielding protrusion $a_1 =$ 2.5 mm, the gap between the kicker cylinder and the ground plate $a_2 = 8$ mm, the protrusion thickness is $a_3 = 1$ mm. These geometries differs by the length of the protrusion $h$ and period $L$ , which are indicated in Table 1.

*Discussion*

1. All geometries (#1 –# 5) have similar kicking efficiencies (within a factor of 1.5).
2. From the point of view of the kicker efficiency, the best case is #1, with plates.
3. The case #2 with cylinders has the efficiency by 12% lower and the field width by 7% larger. A possible additional complication is a higher capacitance between neighboring electrodes. Cases 3-5 show that it can be corrected by screening protrusions between electrodes by expense of the kicking efficiency. Also, capacitance to ground is increasing as well.
4. The choice of the electrode geometry depends on the details of the mechanical design and voltage of available pulse generators.

**References**


1. V.Lebedev, Project X Document 849-v1, available at [http://projectx-docdb.fnal.gov/cgi-bin/RetrieveFile?docid=849&version=1&filename=MEBTr.pdf](http://projectx-docdb.fnal.gov/cgi-bin/RetrieveFile?docid=849&version=1&filename=MEBTr.pdf)

2. V.Lebedev, Project X Document 889-v1, available at http://projectx-docdb.fnal.gov/cgi-bin/RetrieveFile?docid=889&version=1&filename=MEBT_Kicker_Design.pdf
3. A.Shemyakin, L. Prost, Project X Document 842-v2, available at http://projectx-docdb.fnal.gov/cgi-bin/ShowDocument?docid=842
4. B. Fomel et al., Preprint Budker INP 96-11, 1996
5. Wikipedia: http://en.wikipedia.org/wiki/Capacitance